Effect of the channeling of ultrarelativistic electrons on the spectrum of coherent bremsstrahlung of type *B*

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The spectrum of coherent bremsstrahlung of type B generated in a diamond single crystal by 300-MeV electrons has been measured. When the electrons move in directions far from crystallographic directions, the emission spectrum can be described well by the standard theory of coherent bremsstrahlung. Under channeling conditions, there is a significant discrepancy with the theory, and the emission spectrum broadens. It is suggested that this result is a consequence of a "splitting" of a spectral line due to the effect of the average potential of the crystallographic axis or plane.

Coherent processes of type B (Ref. 1), which are distinguished from those of type *A* in that the longitudinal momentum transferred to the crystal is also quantized, have recently attracted increased interest.[2,3] In particular, it was suggested in Ref. 4 that coherent bremsstrahlung of type *B* generated by electrons of intermediate energy ($E_0 \lesssim 100$ MeV) might be used as a source of quasimonochromatic photons with an energy $\omega = (0.7\text{–}0.9)E_0$ and a spectral width $\Delta\omega/\omega \leqslant 1\%$.

According to the theory of Ref. 1, the intensity and spectral width of coherent bremsstrahlung of type *B* reach a maximum and a minimum, respectively, when the electrons are incident along close-packed axes of the crystal. As the misalignment angle increases, the intensity falls off, and the spectral width increases. For an electron energy of 300 MeV and a diamond crystal with a thickness of 0.171 mm, for example, a deviation of 10 mrad from the ⟨111⟩ axis reduces the intensity at the peak by 30% and doubles the spectral width in comparison with the results for an axial orientation. On the other hand, we know that particles which are moving along a crystallographic axis have a significant probability to be captured into a channeling regime. Such an event could affect the spectrum of coherent bremsstrahlung of type *B*. Since there has been no experimental study of the effect of channeling on the spectrum of coherent bremsstrahlung to type *B*, such a study is clearly of interest.

The experiment was carried out at the Tomsk synchrotron with an electron beam with an energy width $\Delta E_0/E_0 \leqslant 1\%$ and a divergence $\Delta\vartheta \approx 0.2\text{–}0.3$ mrad. The emission was collimated to an angle $\vartheta_\gamma = 0.6$ mrad. The target was a single crystal of natural diamond in the ⟨111⟩ orientation with a thickness of 0.171 mm. The degree of mosaic structure was no worse than 0.2 mrad. The error in the alignment of the crystal was no worse than 0.2 mrad.

The measurements were carried out with the help of a double magnetic γ spec-

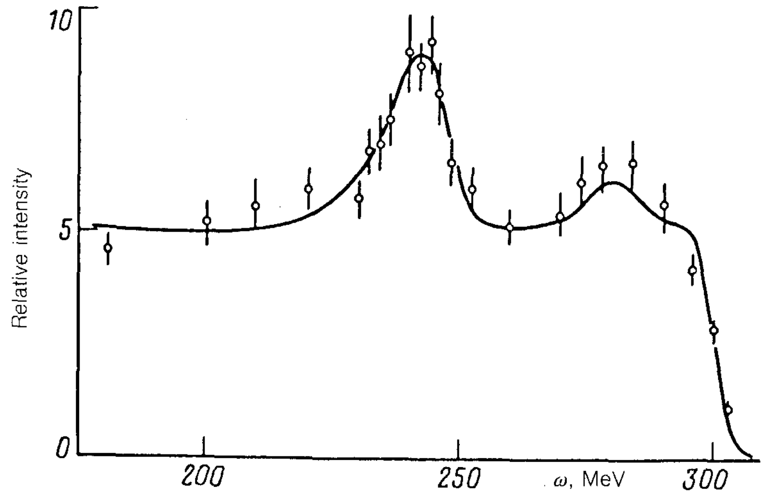

FIG. 1. Intensity spectrum of coherent bremsstrahlung of type B in the absence of channeling. Points—Experimental; line—smoothed theoretical curve.

trometer. The dependence of the efficiency of this spectrometer on the γ-ray energy was found experimentally by comparing the measured spectrum from an amorphous target with the Schiff spectrum, which can be calculated accurately for any target thickness. The resolution (FWHM) of the spectrometer was about 5 MeV for a γ-ray energy $\omega = 250$ MeV (Ref. 5).

Figure 1 shows the measured intensity spectrum of the coherent bremsstrahlung of type B for an electron energy $E_0 = 300$ MeV. The angular deviation from the $\langle 111 \rangle$ axis is $\psi_V = 8$ mrad, and the angular deviation from the $(11\bar{2})$ plane is $\psi_H = 2.2$ mrad. This orientation corresponds to an angular region in which coherent bremsstrahlung of type B occurs.[4] Also shown here is a theoretical spectrum for the same conditions. This theoretical spectrum has been "smoothed" by means of a specified instrumental resolution, and it has been normalized to the incoherent pedestal. The buildup of multiple-scattering angle as the particle passes through the target was considered in the calculations. The effect of the nonaxial collimation of the emission from the scattered electrons which are moving in directions other than the collimator direction was also taken into account. The calculation method, which is based on the theory of coherent bremsstrahlung of type B, is described in detail in Ref. 6.

Figure 1 shows that there is a good agreement between the theoretical and experimental spectra when the crystal orientation corresponds to motion of electrons in directions far from crystallographic directions. The intensity of the coherent bremsstrahlung of type B is comparable to the intensity of the incoherent pedestal, and the intrinsic spectral width (FWHM) is no worse than 5%, despite the significant thickness of this crystal.

The rest of the figures show experimental and theoretical intensity spectra for an

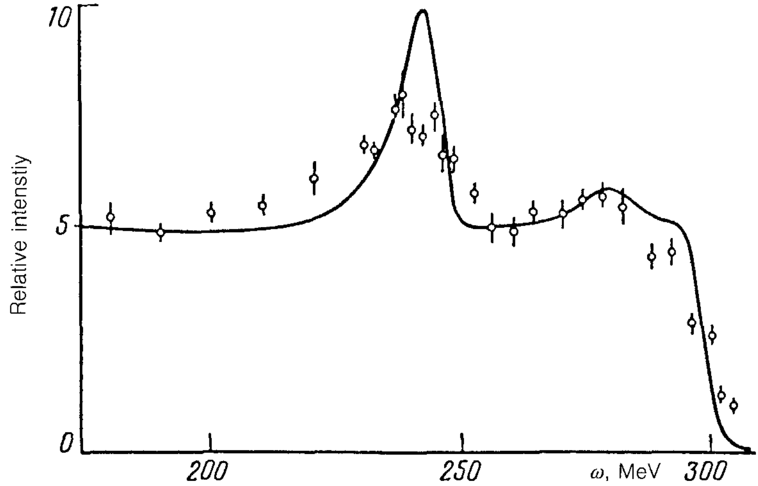

FIG. 2. Intensity spectrum of coherent bremsstrahlung of type B for conditions corresponding to ⟨111⟩ axial channeling. Points—Experimental; line—theoretical.

axial orientation of the crystal (Fig. 2) and for a planar orientation [the $(11\bar{2})$ plane; Fig. 3)]. The angular deviation from the axis is $\psi_V = 6$ mrad. Comparison of the experimental and theoretical spectra shows that the spectra of coherent bremsstrahlung of type B become distorted under channeling conditions. The center of gravity of the peak corresponds to the theory, but the height of the peak is smaller than the theoretical height by a factor of nearly 2, and the width at half-maximum is considerably greater.

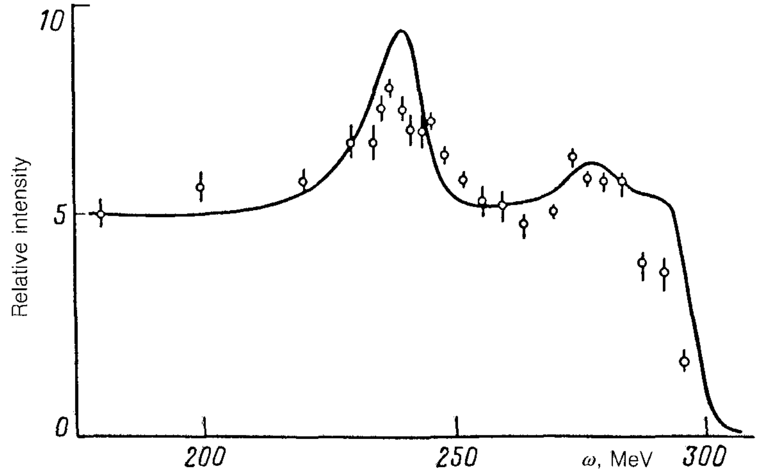

FIG. 3. Intensity spectrum of coherent bremsstrahlung of type B for conditions corresponding to $(11\bar{2})$ planar channeling. Points—Experimental; line—theoretical.

TABLE I.

Orientation	$\Delta\omega_p$ MeV	$\Delta\omega_{\mathrm{expt}}$ MeV	ω_{chan} MeV
< 111 >	10.5	24±3	3.4
(112)	13.5	20±3	0.8
RANDOM	15.5	15±1	-

The most likely reason for the observed effect is a "splitting" of the coherent bremsstrahlung peak due to channeling. The possibility that such an effect might occur has been discussed in several places in the literature (e.g., Refs. 7 and 8). According to Refs. 7 and 8, the potential of the axis or plane may give rise to sum and difference (combinational) frequencies along with the main peak (with an energy ω_{CB}) in the coherent bremsstrahlung. These additional peaks would have energies $\omega_k = \omega_{\mathrm{CB}} \pm k\omega_{\mathrm{chan}}$ ($k = 1,2,3,\dots$), where ω_{chan} is the energy of the radiation by the channeled particle. For an electron energy $E_0 = 300$ MeV, the single frequency ω_{chan} would be replaced by a continuous spectrum, with a frequency corresponding to the maximum:[9]

$$\omega_{\mathrm{ax-chan}} = 2\gamma^2\sqrt{2U_0/mc^2\gamma}/a_s,$$

$$\omega_{\mathrm{pl-chan}} = 2\pi E_0\sqrt{2U_0/m^2c^4}/d,$$

where u_0 is the depth of the potential well of the axis or plane, a_s is the screening radius, and d is the distance between planes. The notation is otherwise standard.

In this case the "combinational splitting" would obviously be seen as an effective broadening of the spectrum of coherent bremsstrahlung of type B. Table I shows the widths of the experimental ($\Delta\omega_{\mathrm{expt}}$) and theoretical ($\Delta\omega_{\mathrm{theo}}$) spectra for three orientations of the crystal. Also shown here are typical values of the energy of the radiation emitted during the channeling. We see from this table that the passage of a particle along an axis is accompanied by a large increase in the spectral width in comparison with the case of a planar orientation. This result correlates well with the typical energies of the radiation emitted during channeling for these orientations. When the electrons move in a direction not along an axis or a plane, the widths of the experimental and theoretical spectra are the same.

With decreasing energy of the electrons (or, especially, of positrons), the number of levels and their width decrease. In this case the splitting effect should thus be seen in its pure form.

We conclude with the following observations.

a) The process of coherent bremsstrahlung of type B can be utilized to generate quasimonochromatic photon beams. The characteristics of these beams can be calculated within a given error for the case in which the direction of the electron beam does not coincide with a crystallographic direction.

b) A quantitative study of this splitting will require electron (or positron) beams with $E_0 \lesssim 100$ MeV and a spectrometer resolution $\Delta\omega \leqslant \omega_{\text{chan}}$.

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